The gray areas indicate the greatest challenges—projecting socioeconomic characteristics at the sub-county level. Yet, as described previously in Text Box 4-7, sub-county projections may be essential to some user communities, such as those conducting climate impact assessments, and so new methods may need to be developed and applied.

Scenarios may be able to inform population projections where uncertainty is high, such as sub-county projections of socioeconomic variables. Since the future remains uncertain, scenarios can be used to consider the impact of specific changes (i.e., "what if?" scenarios) or various potential futures based on combinations of assumptions.

Key Points: Capabilities for Developing U.S. Population Scenarios

1. Scenarios and projections differ in terms of plausibility and comprehensiveness: scenarios typically are more comprehensive than projections because of the greater number of elements they include in describing the future state of the world. However, projections, unlike scenarios, are sometimes assigned probabilities. Scenarios are one way of handling the large uncertainty about future conditions that can be associated with projections.

2. Practically speaking, scenarios can be as important as projections for state and local policy issues: scenarios can assist the researcher in quantifying a plausible storyline, bracketing a range of outcomes, or supporting planning to achieve aspirational scenarios.

3. Global scenarios can inform and support the development of national and sub-national scenarios; however, consistency should not constrain national scenarios from reflecting nationally relevant factors and conditions.

4. The user community faces tradeoffs when applying existing tools, data, and methods to projections that incorporate different population attributes and different levels of spatial and temporal detail.

5. Applying existing models, collecting important data, and developing new techniques will all be part of developing population projections to suit a variety of purposes, as well as transforming qualitative and quantitative scenarios into quantitative population projections.

6. Scenarios can play a useful role in exploring projections of socioeconomic, spatial, or temporal detail where confidence in data and methods is low.

5. Key Insights from Workshop Discussions

- Developing population projections that have a high level of spatial resolution and include socioeconomic characteristics of the population is difficult and sometimes infeasible. Projecting over a long time horizon increases the uncertainty.

Many users indicated a desire for higher resolution projections as well as a list of population characteristics. Small-area or higher-resolution (i.e., sub-county) population projections are used for a variety of planning and budgeting purposes (e.g., land use, public school construction, conservation strategies, future water consumption). Population characteristics that were frequently mentioned included age, sex, urban/rural or density, education, health status, and

income. However, the production of well-grounded projections involves a tradeoff between spatial resolution and population characteristics; this tradeoff becomes even more pronounced when projecting on the time scales typically used in global change assessments. In particular, many workshop participants expressed unease in projecting non-demographic characteristics at sub-national scales. Even for projections based on demographic factors, there is strong evidence that projection uncertainty grows with finer spatial resolution and with longer time horizons. Trying to do all three—non-demographic factors, fine resolution, and long time frames—is challenging and may not be feasible with current understanding and available data.

- Sub-county population projections are needed for climate impacts research and adaptation planning.

Although projecting sub-county populations over longer time periods poses significant challenges, they are needed for understanding the implications of climate change for the United States. Hierarchical approaches have been used to develop such fine-scale population estimates and forecasts for a wide array of analyses. In this approach, national, state, or county projections are developed by authoritative sources (e.g., U.S. Census or state demographers), typically using some variant of the cohort component method. Higher resolution projections for specific small areas are made using a variety of approaches including trend extrapolation and ratio methods, cohort-component methods (e.g., Hamilton-Perry), housing unit allocation approaches, structural or "knowledge-based" models (e.g., economic-demographic, urban systems), and microsimulation or agent-based models. Sub-county population projections are available for many states, and there are guidelines for preparing these projections (see, for example, Smith et al., 2013; Chapin and Diaz-Venegas, 2007). In some states, local knowledge about future development and other factors is used to adjust sub-county projections.[7] The private sector also prepares localized population projections. Currently, however, there is no uniform method used across the country for sub-county population projections.

Projecting sub-county populations has become increasingly important as understanding climate change impacts on human populations and adaptive decision making have become new foci for the climate change community. For example, sea level rise will not affect coastal county populations equally; communities closer to the ocean will be more impacted and have a greater need to adapt than those further away (within the same county). Sub-county population projections are an active area of research and investigators are evaluating the usefulness of new data and methods such as satellite remote sensing, cell phone data, and multiple regression approaches. Given the need for high spatial resolution population data, research to address concerns about uncertainty is a priority. A systematic evaluation of the various approaches and their utility for specific applications would provide important insights for projecting sub-county populations for climate impact studies.

[7] See, for example, Arizona population projections at: https://population.az.gov/population-projections.

- Demographic scenarios and projections are not predictions of the future; however, they should be well-grounded characterizations of plausible future outcomes.

Criteria for judging the quality of a scenario or projection should be based not on whether it is an accurate and precise *prediction* of future conditions, but on whether it is plausible, grounded in data, developed using trusted methods, and internally consistent. For many demographers and practitioners, this may involve using their methods in different ways than is typically the case. Current practice focuses on developing a population forecast (i.e., the most probable future) and using alternative specifications of demographic components (e.g., using high/low fertility rates, mortality rates, or migration) to bracket the forecast in order to account for uncertainty. In some cases, the effects of differing assumptions on future populations are explored to illustrate the sensitivity of the forecast to these assumptions. Population scenarios and projections can also be used to support particular political, economic, or social goals through, for example, the development of aspirational views of the future. Population scenario efforts may include non-demographic variables (e.g., education, health status, income), as well as alternate ranges of demographic variables—"what if"–type scenarios—to describe a broader range of future populations. Engaging additional communities beyond demographers—such as regional economists, urban planners, and GIS experts—will be necessary to design broader scenarios of societal changes that are capable of informing demographic projections. Climate offices in large cities are another source of scenario information; they may offer additional insights for understanding how to move forward with scenarios and projections.

- Maintaining and improving demographic data is essential to producing high-quality population projections for use in global change scenarios.

The importance of preserving and strengthening existing data collection efforts and datasets, such as the American Community Survey (ACS), IRS datasets, National Center for Health Statistics, and state offices of vital statistics, was noted by several workshop participants. Consistent and cohesive collection of population, social, housing, and economic characteristics facilitate the development of population projections. Moreover these data are familiar to many users as they are routinely used by a wide range of groups including Federal, state, and local agencies, NGOs, emergency planners, the private sector, and the general public. The ACS, in particular, was mentioned as it is an important source of non-demographic information critical for advancing our understanding. However, the ACS collects these data through surveys and there is interest in developing more efficient and effective ways to get at the same data.

Participants noted that changes in information technology are opening up new possibilities. Big data could be potentially quite useful, although data quality may be an issue. For example, these data may not be representative of the whole population and therefore may not be suitable for scientific uses. There are also privacy concerns and potential restrictions on sharing data. The widespread use of GPS, such as in cell phones, may provide data for tracking temporary migration, such as vacation travel and commuting patterns (i.e., day vs. night populations).

Satellite remote sensing has also opened new opportunities to track urban change (e.g., National Urban Change Indicator) and inform population projections.

- Methods for producing national-level, spatially explicit population projections are at relatively early phases of development; efforts to compare methods and model simulations would facilitate further development of methods as well as help define the research agenda

Nationally benchmarked, spatially explicit population projections would provide data needed for climate impacts research, development of adaptation options, and the National Climate Assessment. The climate change science community has used formal processes to compare model simulations to observations and to each other. The current Coupled Model Inter-comparison Project (CMIP5) provided critical support to the 5th Climate Assessment Report of the United Nations (IPCC AR5) and along with the previous CMIP (CMIP3), the National Climate Assessment. The CMIP process has resulted in significant improvements in our understanding of underlying processes, identification of key uncertainties in climate modeling, and increased the usefulness of General Circulation Model (GCM) simulations for climate impacts research and assessment. There exists a sufficient nucleus of national, spatially explicit population modeling efforts to make a "PopMIP" a worthwhile endeavor, providing insights and progress similar to those for the CMIP effort. Although the U.S. Census Bureau has not been involved much in USGCRP, it would be a central player in any PopMIP exercise.

Another outcome of a PopMIP would be a rigorous identification of highly influential yet uncertain population drivers, pointing the direction to the most important research areas. Hybrid modeling approaches (combining top-down and bottom-up, and merging gravity- and agent-based modeling) could also be evaluated relative to existing methods. A PopMIP would also promote sharing and transparency of data inputs, assumptions, modeling approaches and simulation results.

- Developing plausible alternative futures for migration, particularly internal migration, would provide the most added value to a U.S. population scenarios effort.

Migration continues to be the most uncertain demographic factor affecting population projections at sub-national scales. Extrapolation of historic trends, simple rule-based methods such as gravity models, and ad hoc assumptions relating population movement to other, especially economic, variables have all been used to project population movements between regions and states and within states. The danger of these approaches is that major shifts in population migration patterns that could be important for climate impact studies and assessments would be missed. More sophisticated modeling approaches have not been used; this is due, in part, to a lack of understanding of the dynamics of population migration and the influence of factors such as regional economics, income, environmental amenities, density/congestion, public

policies, and housing markets. Further, these influences may not exhibit the same structural relationships with population in different parts of the country. At the sub-county level, applied demographers have generally ignored such models when developing population forecasts for sub-county areas, as they do not perform better than simpler models.

Developing such knowledge-based projections would be particularly useful for adaptation studies. Additional "levers" would allow the analyst to explore feedbacks from climate change and adaptation policies to population growth and economic development. Engaging additional social sciences disciplines—such as human ecology, regional economics, population geography, environmental sociology, and urban planning—could provide fresh views on modeling population migration. In addition to research to develop such models, a scenario effort to explore the effect of major population shifts is also needed to support the National Climate Assessment.

- It would be useful for U.S. population scenarios to be consistent with global scenarios; however consistency should not overly constrain the development of U.S. scenarios.

Consistency with global scenario efforts, such as SRES, SSPs, and RCPs, is beneficial. Consistency with these efforts provides important context for interpreting results from analytic studies and assessments. It also promotes internal consistency of climate impacts studies, i.e., the scenario that drove the climate model and simulation results is consistent with the scenario that drove the population projection results. Climate assessments are facilitated when the climate impacts literature uses consistent scenarios as they can be compared and combined to yield important insights. However, the flexibility to tailor U.S. scenarios to various needs, especially at the finer geographic resolution needed for adaptation, needs to be preserved. The challenge for the U.S. scenario enterprise is to develop methods such that top-down and bottom-up merging of qualitative scenarios and quantitative simulation results are feasible and credible.

Selecting the appropriate global scenario that may be used to align a U.S. scenario effort can be complicated. The SRES are widely known and used; given the time lags in publishing research results, it seems prudent to maintain some connection with or acknowledgement of these global scenarios. Newer generation scenarios (RCPs) are being used to drive global climate simulations and maintaining internal consistency would suggest an embrace of these scenarios. Yet a third option is the SSPs, which are designed to better link to mitigation and adaptation decision making. It would be helpful to determine how much these scenarios overlap in the population dimension so that equivalencies can be determined. Developing such a crosswalk would be a useful first step in understanding which global scenario is preferable for a given purpose.

Another important issue related to the first question is how population information is to be passed from global models to national, state, and county levels—i.e., how "tight" linkages should be across geographic scales. One approach would be to hard-link national population totals only and let sub-national models distribute population across the landscape without further guidance from global scenarios. A second approach would go further and use "soft" linkages from global